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ABSTRACT

This lesson is the second of a two-part series on anaerobic digestion. Topics discussed include classification of digester by function, roof design, and temperature range, mixing systems, gas system components, operational control basics, and general safety considerations. The lesson includes an instructor's guide and student workbook. The instructor's guide contains a description of the lesson, estimated presentation time, instructional materials list, suggested sequence of presentation, reading lists, objectives, lecture outline, narrative of the slide/tape program used with the lesson, references, and student worksheet (with answers). The student workbook contains plant flow diagrams, objectives, glossary, discussion material, references, and worksheet. Discussion material is presented in seven sections titled: digester classification (tanks), boilers and heat exchangers, mixing systems, gas system, operational control, sampling and testing, and safety. (JN)

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SLUDGE TREATMENT

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COURSE # 166

ANAEROBIC DIGESTION II

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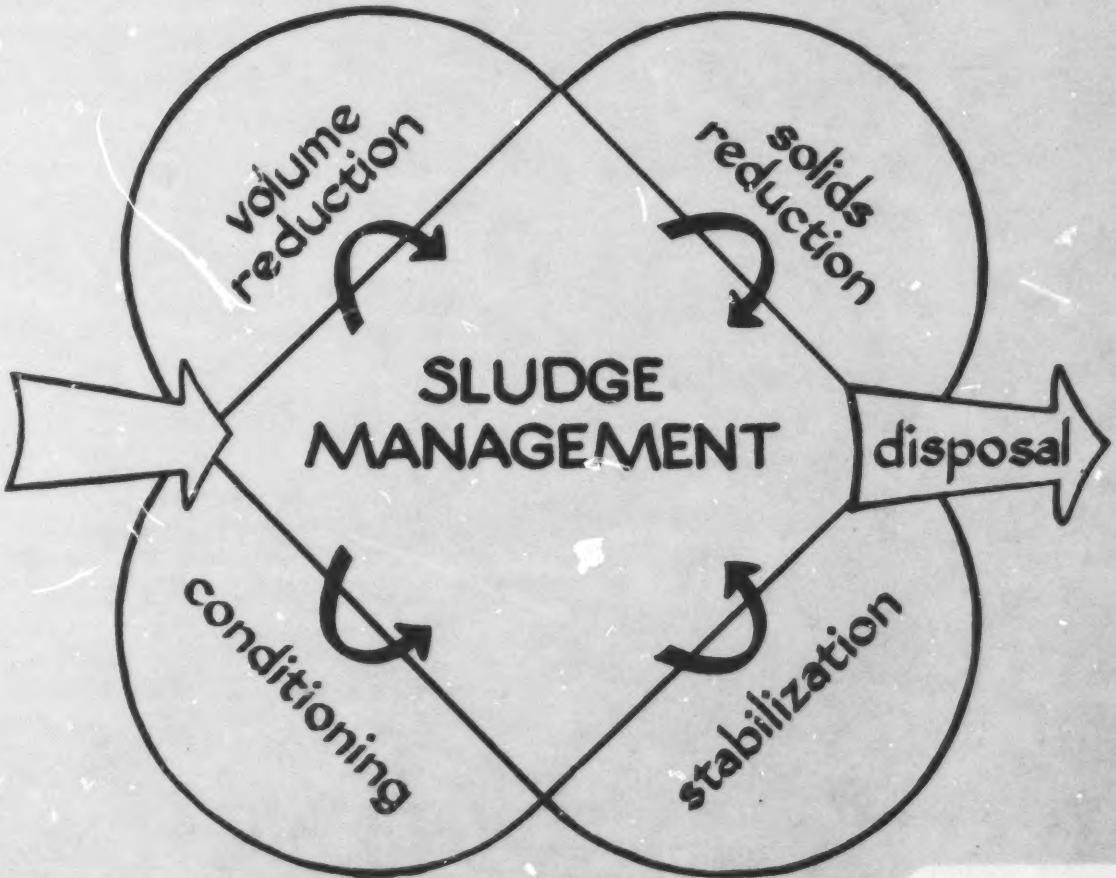

INSTRUCTOR'S GUIDE

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ANAEROBIC DIGESTION II

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ANAEROBIC DIGESTION II

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ANAEROBIC DIGESTION II

Lesson Description

This lesson is Part II of a two-part series on Anaerobic Digestion. Part I should be viewed before Part II. This lesson discusses the classification of digester by function, roof design and temperature range. The lesson also discusses mixing systems, gas system components, operational control basics, and general safety.

Estimated Time

Student preview of objectives	5-10 minutes
Presentation of material	40-80 minutes
Worksheet	10-15 minutes
Correct worksheet and discussion	10 minutes

Instructional Materials List

1. Student text "Anaerobic Digestion Part II"
2. Slide Set "Anaerobic Digestion Part II"
3. Slide Projector
4. Screen
5. Examples of gas safety equipment

Suggested Sequence of Presentation

1. Assign Reading - emphasis on flow diagrams, glossary and objectives.
2. Show slide tape programs, or lecture using the slides.
3. Open discussion - reveiw plant flow diagrams, safety equipment, sampling and use of moving averages on trend charts.
4. Assign worksheets.
5. Correct worksheets.

Required Reading

Lesson "Anaerobic Digestion, Part II"

Reference Reading

Operations Manual Anaerobic Sludge Digestion, pages 4-25 through 4-31, 4-16 through 4-18.

Objectives

Upon completion of this lesson the student should be able to do the following:

1. Recall the three digester classifications by function.
2. State which digester performs the majority of digestion.
3. Identify digesters by roof design.
4. Recall the name of the most common digestive operating range.
5. State the temperature range for the mesophilic temperature range.
6. State the normal digestion time for the mesophilic range.
7. Recall the maximum temperature variation allowed for a properly operated anaerobic digester.
8. State the three types of heat exchanges.
9. Recall which type of heat exchanger is the easiest to maintain.
10. Describe the purpose of mixing.
11. Identify basic gas components.
12. Describe the function of the gas components.
13. Recall the typical volatile solid/ft.^{3} loading.
14. Recall a typical volatile acid/alkalinity ratio.
15. Identify the five sample points on an anaerobic digester.

ANAEROBIC DIGESTION II

LESSON OUTLINE

I. Preview
   A. Classification by function
   B. Classification by roof design
   C. Effects of temperature
   D. Mixer types
   E. Gas system
   F. Sample points
   G. Testing
   H. Safety

II. Classification
   A Function
      1. Primary
         a) Receive sludge first
         b) Majority of digestion
      2. Secondary
         a) Follows primary
         b) Sludge gas storage
         c) Multiple digesters - operational flexibility
   B. Roof design
      1. Fixed
         a) Primary
      2. Floating roof
         a) floats on sludge
         b) level controlled by sludge draw off
         c) secondary
         d) corbels prevent roof from falling
      3. Gas Holding
         a) floats on gas
         b) height controlled by gas and liquid draw off rates
   C. Temperature Classification
         a) temperature controls digestion time

b) normal mesophilic
c) 95-98^{o}F
d) 20-30 days
e) not vary more than 1^{o}F/day

III. Boilers and Heat Exchangers
A. Boiler
1. low pressure
2. uses methane
3. alternate source
B. Heat exchanger
1. internal - coils
a) difficult to maintain temperature
2. Steam injection
a) internal
b) both heating and mixing
c) boiler water treatment
d) adds extra water
e) maintenance
3. Direct gas
a) heats and mixes
b) danger
4. External
a) ease of maintenance
b) hot water
c) pre-heat sludge
d) circulate sludge next to hot water coils
e) mixing
f) regular cleaning
5. Temperature Control and Efficiency
a) rate of recirculation
b) Efficiency of boiler
c) BTU value of gas
d) rate of flow
e) temperature of raw sludge

f) efficiency of heat exchanger

g) $1^{o}F$/day

IV. Mixing System

A. Contact of sludge and micro-organisms

B. Mixer

1. compressed gas
2. mechanical
3. pumps

V. Gas System

A. Equipment

1. heat sensitive valve
2. flame arresters
3. pressure reducing valve
4. moisture - sedimentation traps
5. Orifices - manometers
6. gas meters

B. Designed for safety and control

1. corrosive
2. explosive

VI. Operation Control

A. Major areas

1. bacteria
   a) anaerobic
   b) slow
   c) ratio 20:1
2. Food
   a) 5-8% solids
   b) no toxic material
   c) stable pH
   d) constant feed rate
3. Loading
   a) F/M ratio
   b) hydraulic loading

c) 0.03 to 0.1 lbs VS/ft^3

d) 20 days retentive time

4. Mixing

a) artificial best

b) loading 0.4 lbs VS/ft gives natural loading

5. Environmental conditions

a) anaerobic

b) pH 6.8-7.2

c) VA 50-300

d) alk 3,000-600 mg/l

e) VA/Alk 0.25 or below

6. Time

a) controlled by loading and temperature

b) 95-98^{o}F, 20-30 days

VII. Sampling and Testing

A. Sampling points

1. digested sludge

2. digesting sludge

a) thief hole

3. raw sludge

4. supernatant

5. gas

B. Typical test pH, %, moisture, temperature, alk, V.A.

C. pH and temperature

1. raw, digested, digesting, supernatant

D. Flow

1. all points

E. Efficiency

1. T.S., % moisture, VS compared between raw and digested

F. Gas

1. CO_2, Flow

G. Supernatant

1. BOD, S.S. and VSS

H. Control test
   1) VA/Alk ratio
   2) better than pH

I. Plot on 30-day moving averages

VIII. Safety

A. General
   1) rubber-soled shoes
   2) relight burner with caution
   3) Fix leaks ASAP
   4) check for combustible gas and O_2 in tanks

IX. A. Summary

Narrative

Slide #

1. Anaerobic Digestion - This is Part II of a two-part series on the basic theory and operation of anaerobic digesters. The two parts should be viewed consecutively.

2. This program was written by Mr. E. E. "Skeet" Arasmith. The instructional development was done by Priscilla Hardin. Mr. Paul Klopping was the project manager.

3. During this lesson, we will deal with the classification of digesters by function, roof design and temperature, the effects of sludge temperature and ways to control that temperature.

4. We will discuss mixer types, the gas system components, specifically the safety devices and the overall system operation. We will also discuss six factors that effect operational control, some common test points and typical tests and finally there will be an overview of safety considerations.

5. Digesters maybe classified by function as to primary, secondary or gas holding.

6. Primary digesters are the units that first receive the sludge - it is here that the majority of the digestion takes place.

7. Secondary digesters receive digested sludge from the primary digester. They serve essentially as sludge and gas storage areas. The third function which a digester may provide is that of gas holding. Gas holding digesters usually would follow secondary digesters and collect gas from both primary and secondary digesters. Having multiple digesters provides an operational flexibility, especially during start up and digester upset.

8. Primary and secondary digesters may be further classified by roof design as to fixed or floating roof. The gas holder is a type of floating roof.

9. With the fixed roof design, gas is stored in the upper portion of the tank. Gas pressure in the tank is controlled by gas draw off rate and liquid level.

10. On the other hand, with the floating roof design, the roof floats on the sludge. With this design, the gas must be drawn off as it is produced. There is very little gas storage area.

11. Fixed roof digesters can be identified by the fact that the solid concrete roof usually is flush with the top of the walls.

12. On the floating roof digesters the roof may be below or above the walls, and roof guides are visible around the top edge of the digester.

13. Primary digesters are usually the fixed roof type, and secondary digesters are usually the floating roof design.

14. The floating roof allows for unsteady sludge draw off rates so that disposal maybe periodic rather than constant. To prevent the roof from falling to the bottom of the digester, steel or concrete corbels project from the wall of the digester.

15. Digesters that serve the third function, gas holding, require a special roof design. The roof of this type of digester floats high above the sludge and is totally supported by the gas pressure in the digester. Since gas pressure holds up the roof, its position is controlled by rates of gas produced and gas and/or sludge draw off.

16. The dome shaped roof makes the gas-holding digester easy to identify.

17. Besides classifying digesters as to function and roof design, they may be classified by the operating temperature of the digesting sludge. There are three typical temperature ranges: phychrophilic, mesophilic, and thermophilic, the most common of which is the mesophilic.

18. The length of time required for digestion to come to completion is a function of the temperature range. Operating within the mesophilic range at 95-98^{0} F. will normally complete digestion in 20-30 days.

Boilers and Heat Exchangers

19. This temperature should not vary more than 1^{0} F. per day. To maintain this temperature, a boiler and heat exchanger of some type are necessary.

20. The boiler is usually of the low pressure type (less than 300 psi) and fired by the methane in the digester gas. Using the digester gas to fire the boiler reduces overall energy requirements and makes the anaerobic digestion process an energy producer rather than a consumer.

21. Besides having the digester gas available, an alternative energy source such as natural gas is usually required for start up and as back up at times of digester upset. During these incidents, the quality of the gas will deteriorate to the point that proper temperature can no longer be maintained.

22. Along with the boiler, there must be a heat exchanger. There are three basic types: internal, direct gas and external.

23. Internal heat exchangers are usually the hot water type and consist of a set of internal coils through which the hot water passes.

24. Internal heat exchangers are difficult to maintain and require efficient mixing to prevent stratification of the sludge.

25. Another type of internal heat exchanger is the steam injection type - with this style of heat exchange, live steam is bubbled through the digesting sludge both heating and mixing.

26. This type of heating adds extra water to the sludge. Furthermore, it requires special chemical treatment of the boiler make up water and continuous maintenance of check valves to prevent back flow of sludge into the boiler.

27. Direct gas systems consist of an open flame contained in a hollow tube below the sludge surface. This type of heat exchanger both heats and mixes.

28. This type of system offers an obvious safety problem; that is, if the methane within the digester is ignited by the open flame, a violent explosion will occur.

29. External heat exchangers are much easier to maintain than either internal or direct flame and are, therefore, more common. So, let's look at the process when one of the many external heat exchangers is used.

30. Hot water from the boiler is passed through a set of tubes within the heat exchanger. Partially digested sludge is mixed with raw sludge by the sludge recirculation pump and then circulated through the spaces between the hot water tubes and then to the digester.

31. The mixing of partially digested sludge with raw sludge improves heat transfer efficiency. The recirculation pump helps with mixing.

32. To maintain the heat exchanger efficiently, the tubes must be cleaned on a regular basis.

33. Controlling the temperature of the sludge and the overall energy efficiency of the system is primarily dependent upon the BTU value of the gas and the efficiency of the boiler and heat exchanger. The efficiency is also effected by the temperature and feed rate of the raw sludge as well as the recirculation rate of the digested sludge.

34. Remember, the temperature must not vary more than 1^{0} F. per day. Fluctuations of greater than one degree per day, even though within acceptable temperature ranges, will cause digester upset.

Mixing Systems

35. As has been mentioned before, the digestion of raw sludge cannot take place unless the microorganisms within the digester can come in contact with the volatile solids within the sludge.

36. This contact is enhanced by continual mixing of the digesting sludge. Several methods of mixing are used. They include:

37. Compressing the gas that is produced and forcing it back through the digesting sludge, or one of several types of mechanical mixers, or a combination of mechanical mixers and pumps, such as the heat exchanger recirculation pumps.

Gas System

38. As has been mentioned previously, one of the major by-products of the anaerobic digestion process is the production of digester gas, which is mostly methane.

39. Because of the explosive nature of the gas, special equipment is required for safe handling. This is true regardless of the major use of the gas.

40. To prevent flash fires in the digester, flame arresters are installed on the top of the digester as well as all other gas exit points.

41. Heat sensitive valves are installed at various points in the gas system to help prevent explosion as a result of a fire within the gas system.

42. Pressure within the gas system is maintained by a compressor and various pressure regulation valves.

43. The functional quality of the gas is improved by the reduction of moisture and sediment by moisture and sediment traps.

44. The rate of gas flow is measured by sharp edged orifices and indicated on manometers.

45. Gas consumption is measured by the typical gas meter.

46. When digester gas systems are properly designed they operate safely while controlling a steady pressure and removing sedimentation and moisture plus monitoring both gas flow and consumption.

47. Digester gas is not easily stored in a typical gas container due to its corrosive and explosive nature. Therefore, any excess that is produced is consumed via a waste gas burner.

48. To obtain optimum digestion from the digester, six factors must be controlled.

49. They are bacteria, food, loading, mixing, environmental conditions and time.

50. The bacteria of major concern are the methane producers which are strict anaerobes. To protect their enviroment, all air must be prevented from entering the digester.

51. These organisms are rather slow in their digestion process; therefore, a ratio of 20 times more seed organisms than food is required. That is, each day, only one lb. of food should be fed for each 20 lbs. of organisms in the digester. That is why it normally takes 20 days or more to complete digestion.

52. The food should be of high quality.

53. To be high quality, the raw sludge should contain a low volume of water. It should contain no toxic materials, and have a stable pH. The rate and frequency of feed must be constant.

54. Loading refers to both the food to organisms ratio and the hydraulic loading.

55. The food to organisms ratio for conventional operations will range from 0.03 to 0.1 lbs. of volatile solids per cubic foot of digester sludge. Hydraulic loading affects detention time. The detention time must be long enough to allow for complete digestion, which may be 20 days or more.

56. The food must mix with the organisms. Mixing may be natural or artifical. However, artifical mixing gives the best results and reduces dead spots.

57. As mentioned before, the environmental conditions must be strictly anaerobic, and a volatile acids to alkaline ratio of 0.25 or below will maintain a steady pH.

58. Digestion time is relative to temperature and controlled by loading. That is, at 95-98^{0} F. a detention time of 20-30 days should be maintained.

59. To control the digester, it is necessary to monitor regularly at various points. Samples should be collected from raw sludge, digester sludge, digested sludge, supernatant and gas. Digested sludge is usually collected through special sampling holes called thief holes.

60. One or more of these thief holes are located on the roof of the digester.

61. Samples collected from these points should be evaluated by laboratory tests. Test such as pH, percent of moisture, temperature, alkalinity, and volatile acids are among the many required monitoring tests.

62. Raw sludge, digesting sludge, digested sludge, and supernatant are all checked for pH and temperature. These tests should be run and compared at least daily.

63. Sludge and gas flow are measured at all entrance and exit points on the digester.

64. To determine the efficiency of the digester, total solids, percent moisture and volatile solids are run on the raw sludge and compared with digesting and digested sludge. These same tests are conducted on the supernatant to determine its quality and ultimate effect on the other treatment processes.

65. The percent of CO_2 in the digester gas as well as flame color indicates gas quality and digester performance. To determine the effect of supernatant on the other treatment processes, both BOD and S.S. are monitored.

66. The ultimate control tests for digester operations are volatile acids and alkalinity. This ratio indicates impending changes in the pH of the digester and, thus, the health of the methane formers. A change in VA/Alk ratios will indicate possible digester problems long before a change in pH can be measured.

67. For best control, trend charts of all parameters should be established with 30 day moving averages.

68. To prevent accidents with digesters, the following precautions should be considered. Wear rubber soled shoes when walking on the roof. Never smoke around the digester vents. Relight the waste gas burner with caution.

69. Fix gas leaks ASAP. Never enter a partially full or empty digester without checking for oxygen depletion and explosive gases.

70. During this lesson, we have seen that digesters are classified 3 ways: by function, by roof design, and by operating temperature. The mesophilic temperature classification is the most common.

71. We learned that digester temperature is controlled by a heat exchanger and that the sludge temperature must be controlled within 1^{o} F/day.

72. We look at several types of mixers and learned that mixing improves digestion.

73. We previewed the basic components of the gas system and learned that the system is designed to control the pressure of the gas, remove sediment and moisture, measure flow and consumption and protect the digester from fire and explosion.

74. We saw that for proper operational control, the digester must be monitored and special control tests run on the samples collected.

75. And, finally, we discussed some general safety precautions that should be considered when working in and around digesters.

References

"Operations Manual; Anaerobic Sludge Digestion;" EPA, 430/9-76-001, Cinncinati, OH, 1976.

"Manual of Practice #11 Operation of Wastewater Treatment Plants," WPCF, Lancaster Press, Lancaster, PA, 1976.

"Operation of WAstewater Treatment Plants", Kenneth D. Kerri, Sacramento State College, Sacramento, CA, 1980.

ANAEROBIC DIGESTION II

WORKSHEET

1. Digestion may be classified by function. On the list below, place an "X" beside the three terms used to describe these three functions:

   ____ a. digestion
   _X_ b. primary
   ____ c. solids reduction
   ____ d. conditioning
   _X_ e. secondary
   ____ f. gas production
   ____ g. energy cost savings
   ____ h. gas producers
   _X_ i. gas holding

2. Find the correct name for this digester in the above list and write the corresponding letter in the following blank: B.

3. Select the proper name for the most common digester operating range.

   _X_ a. mesophilic
   ____ b. psychrophilic
   ____ c. esophilic
   ____ d. thermophilic
   ____ e. none of the above

4. Select the temperature range for the most common digester operating range.

   ____ a. 65-78° F
   ____ b. 79-95° F
   _X_ c. 95-98° F
   ____ d. 98-108° F
   ____ e. none of the above

5. For a normally operated anaerobic digester operating within the typical temperature range, complete sludge digestion should take place in:

   ____ a. 10-20 days
   _X_ b. 20-30 days
   ____ c. 30-35 days
   ____ d. 40-50 days
   ____ e. none of the above

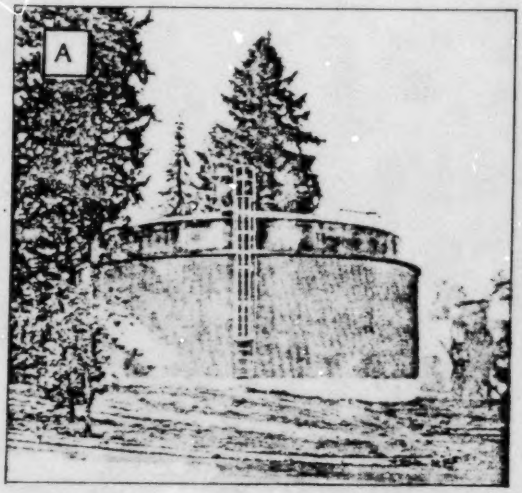
6. Using the pictures below, identify each of the digesters by roof design.

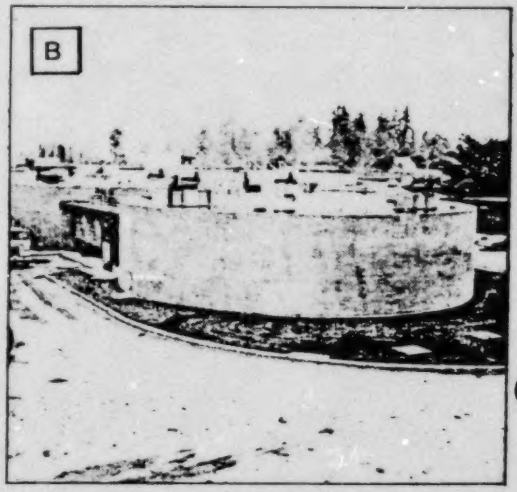
A. gas holding

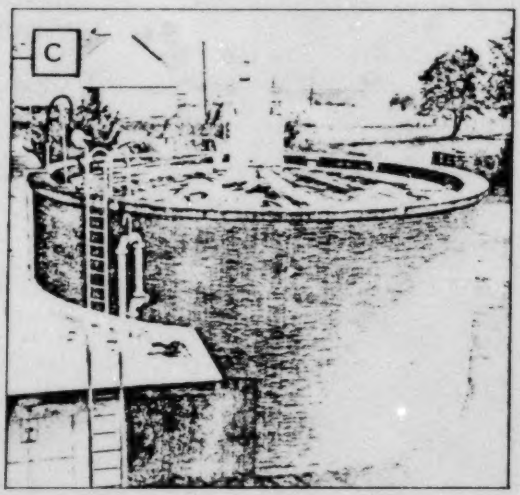
B. fixed

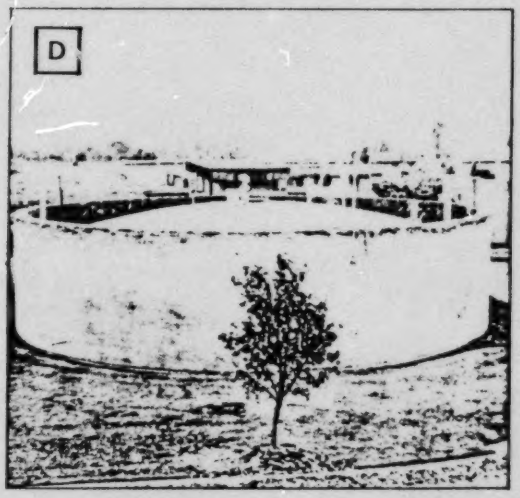
C. floating

D. floating









7. In order to maintain ar anaerobic digester in optimum condition, the digester sludge temperature should not change more than _____ degrees F. per day.

_____ a. 4
_____ b. 3
_____ c. 2
__X__ d. 1
_____ e. none of the above

8. From the list below, select the three most common types of heat exchangers.

_____ a. internal combustion engine
__X__ b. direct gas flame
_____ c. low pressure
_____ d. coil type
__X__ e. internal
_____ f. draft tube
__X__ g. external
_____ h. boiler

9. From the previous list, indicate the type of heat exchanger that offers the easiest maintenance.

G

10. The major purpose for mixing is to: (select one)

__X__ a. bring food and microorganisms into contact.
_____ b. break up the scum blanket
_____ c. reduce energy requirements by circulating heated sludge.
_____ d. release gas from the sludge particles.

11. Match the list of gas handling equipment on the left with the list of functions on the right. (An answer may be used more than once.)

__D__ flame arresters
__E__ waste gas burner
__B__ gas meter
__D__ heat sensitive valve
__C__ sharp edged orifice
__A__ moisture traps
__A__ sediment traps

a. improve gas quality
b. measure gas consumption
c. measure gas flow
d. safety
e. disposal of excess gas

12. Typical volatile solids/ft.^{3} loadings for an anaerobic digester might be:

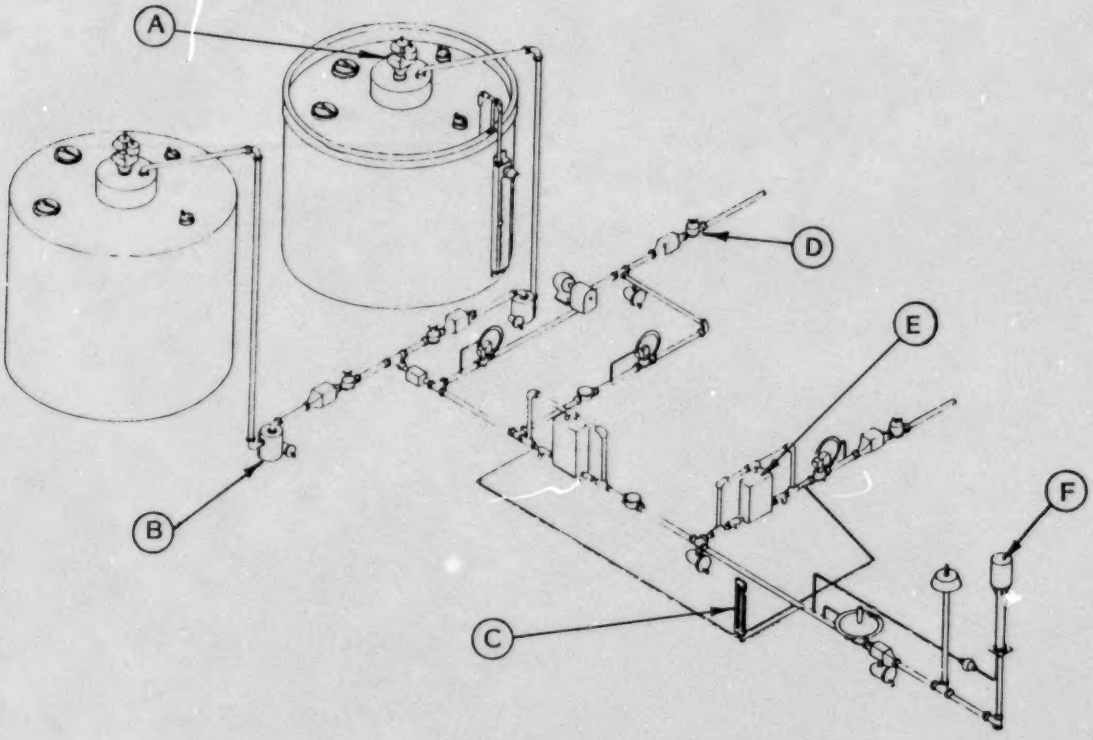
_____ a. 0.004 to 0.04 lbs./ft.^{3}

_____ b. 0.04 to 0.4 lbs./ft.^{3}

__X__ c. 0.03 to 0.1 lbs./ft.^{3}

_____ d. 0.03 to 1.0 lbs./ft.^{3}

_____ e. all of the above



13. Using the drawing above, match the items indicated with the description.

__A__ flame arrester

__F__ waste gas burner

__E__ gas meter

__D__ heat sensitive valve

__B__ moisture and sediment traps

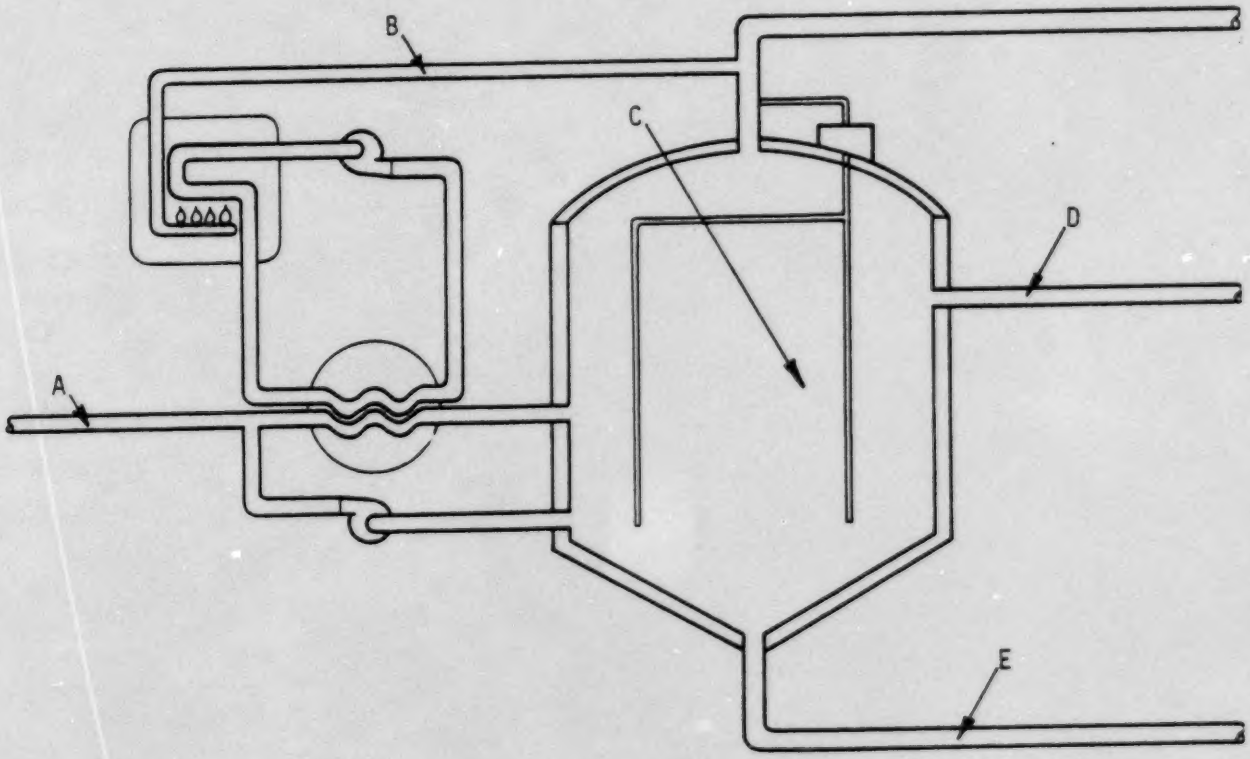
__C__ manometers

14. The most common volatile acids to alkalinity ratio for an anaerobic digester would be:

_____ a. > 0.25
_____ b. > 150
_____ c. 0.4
__X__ d. < 0.25
_____ e. < 0.4

15. Using the diagram below, indicate what material is being sampled at each point.

__D__ supernatant
__A__ raw sludge
__C__ digesting sludge
__B__ gas
__E__ digested sludge



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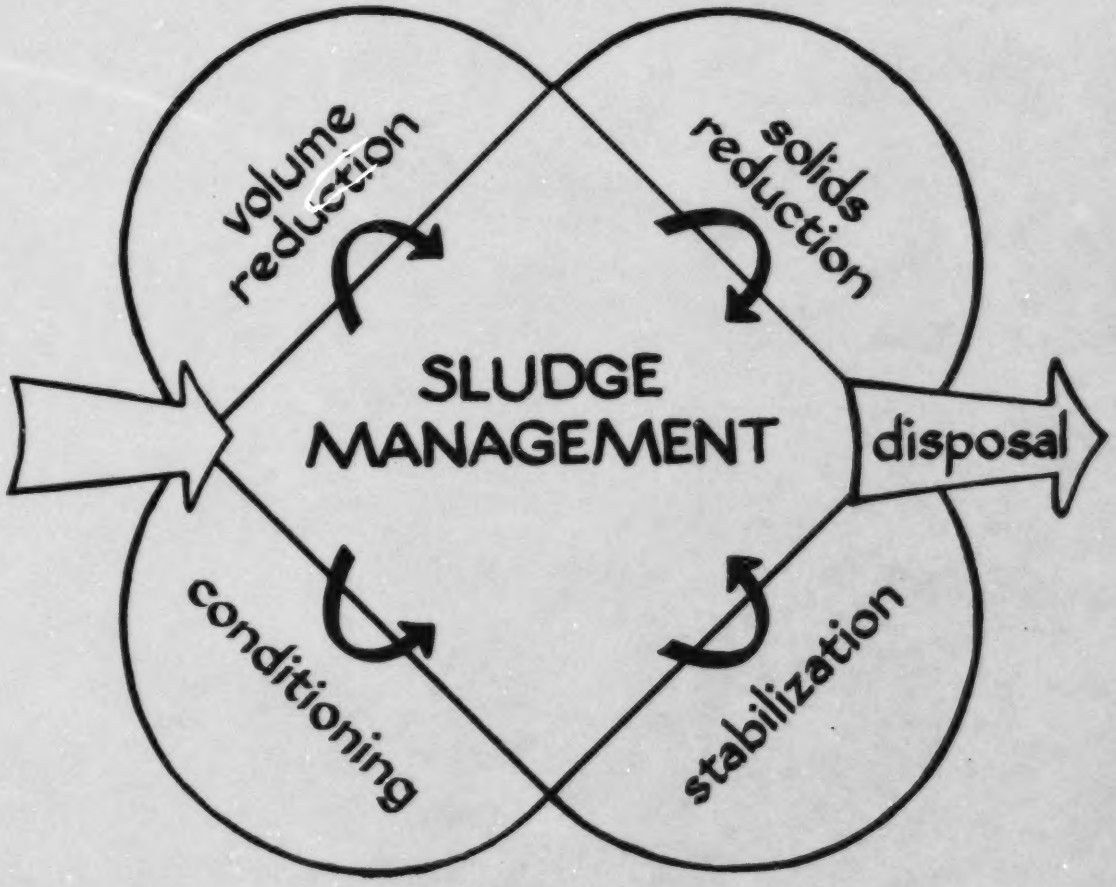
COURSE # 166

ANAEROBIC DIGESTION II



STUDENT WORKBOOK

SE041597

Prepared by
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ANAEROBIC DIGESTION II

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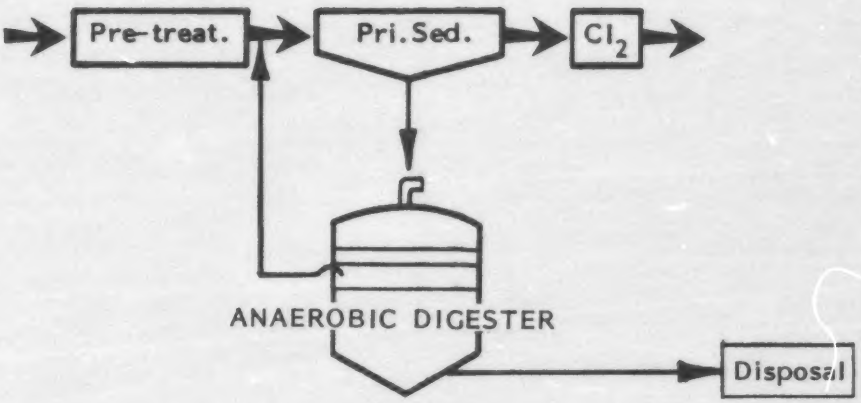
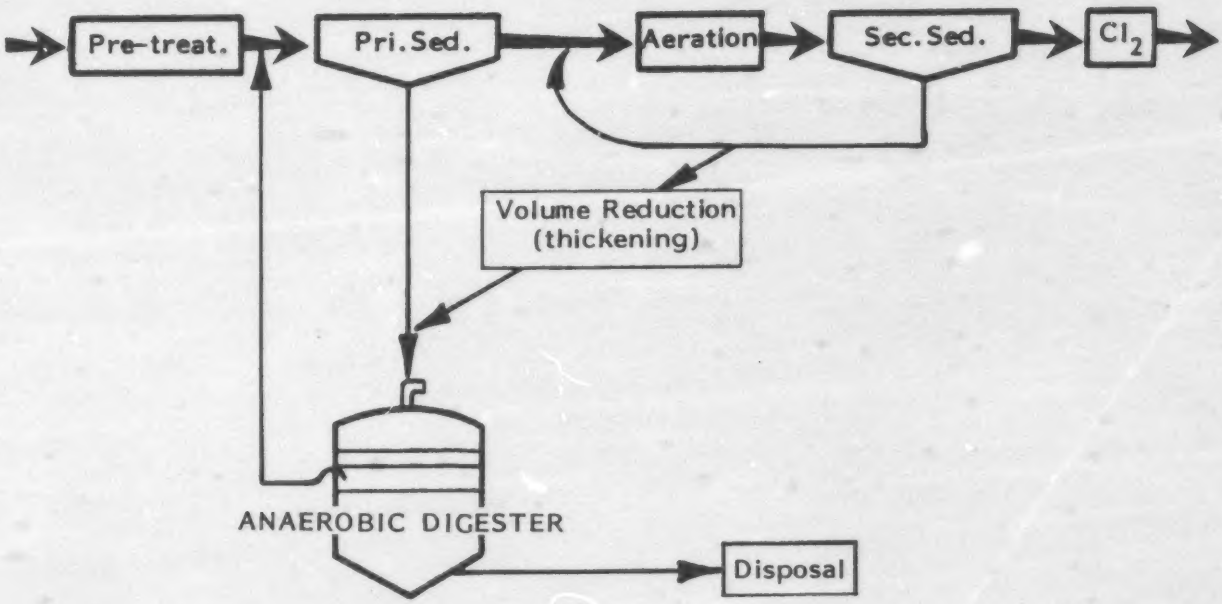
PLANT FLOW DIAGRAMS

PRIMARY PLANT



SECONDARY PLANT



ANAEROBIC DIGESTION II

Objectives

Upon completion of this lesson the student should be able to do the following:

1. Recall the three digester classifications by function.
2. State which digester performs the majority of digestion.
3. Identify digesters by roof design.
4. Recall the name of the most common digestive operating range.
5. State the temperature range for the mesophilic temperature range.
6. State the normal digestion time for the mesophilic range.
7. Recall the maximum temperature variation allowed for a properly operated anaerobic digester.
8. State the three types of heat exchanges.
9. Recall which type of heat exchanger is the easiest to maintain.
10. Describe the purpose of mixing.
11. Identify basic gas components.
12. Describe the function of the gas components.
13. Recall the typical volatile solid/ft.^{3} loading.
14. Recall a typical volatile acid/alkalinity ratio.
15. Identify the five sample points on an anaerobic digester.

ANAEROBIC DIGESTION II

GLOSSARY

Manometer - An instrument for measuring pressure; usually it consists of a U-shaped tube containing a liquid, the surface of which in one end of the tube moves proportionally with changes in pressure on the liquid in the other end. The term is also applied to a tube type of differential pressure gage.

Mesophilic digestion - Digestion by biological action at or below 113 degrees Fahrenheit.

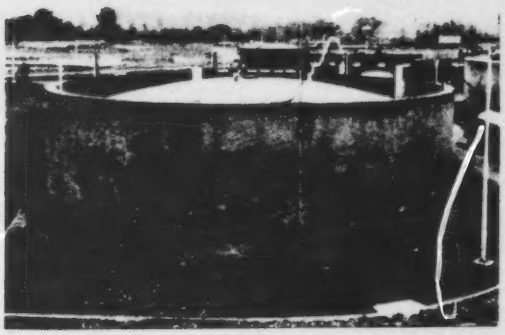
Orifice - An opening in a plate, wall, or partition. In a trickling filter distributor the wastewater passes through an orifice to the surface of the filter media. An orifice flange set in a pipe consists of a slot or hole smaller than the pipe diameter. The difference in pressure in the pipe above and below the orifice may be related to flow in the pipe.

Psychrophilic digestion - Digestion by biological action at or above 68 degrees Fahrenheit.

Thermophilic digestion - Digestion by biological action at or above 113 degrees Fahrenheit.

Thief hole - A digester sampling well.

Digester Classification



Anaerobic Digestion - Part II of a two-part series on the basic theory and operation of anaerobic digesters. The two parts should be viewed consecutively.

This program was written by Mr. E. E. "Skeet" Arasmith. The instructional development was done by Priscilla Hardin. Paul Klopping was the project manager.

During this lesson, we will deal with the classification of digesters by function, roof design and temperature, the effects of sludge temperature and ways to control that temperature.

MIXER TYPES

GAS SYSTEM COMPONENTS
* safety devices
* operations

OPERATIONAL CONTROL
* 6 factors
* test points
* typical tests

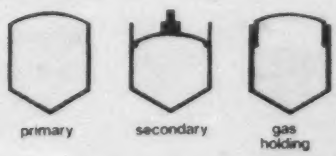
SAFETY CONSIDERATIONS

We will discuss mixer types, the gas system components, specifically the safety devices and the overall system operation. We will also discuss six factors that effect operational control, common test point and typical test and finally there will be an overview of safety considerations.

Digesters may be classified by function as to primary, secondary or gas holding.

Primary digesters are the units that first receive the sludge - it is here that the majority of the digestion takes place.

Classification by Function

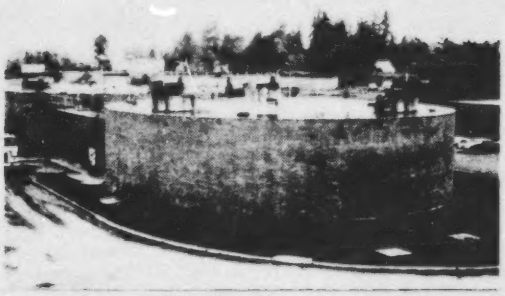


Classification by Roof Design

Secondary digesters receive digested sludge from the primary digester. They serve essentially as sludge and gas storage areas. The third function which a digester may provide is that of gas holding. Gas holding digesters usually would follow secondary digesters and collect gas from both primary and secondary digesters. Having multiple digesters provides an operational flexibility, especially during start up and digester upset.

Primary and secondary digesters may be further classified by roof design as to fixed or floating roof. The gas holder is a type of floating roof.

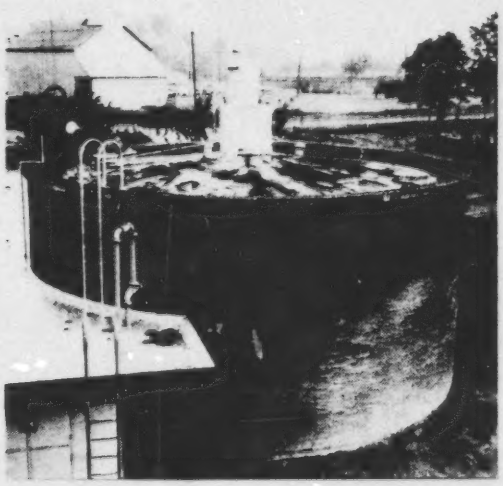
FIXED ROOF DESIGN



With the fixed roof design, gas is stored in the upper portion of the tank. Gas pressure in the tank is controlled by gas draw off rate and liquid level.

On the other hand, with the floating roof design, the roof floats on the sludge. With this design, the gas must be drawn off as it is produced. There is very little gas storage area.

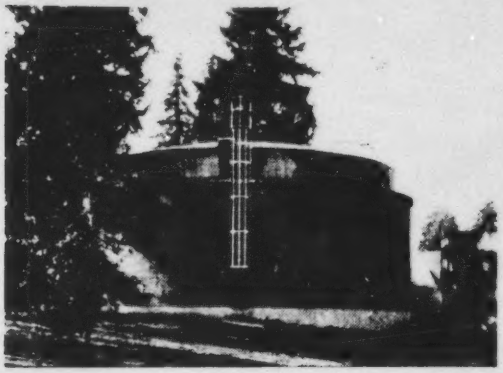
FLOATING ROOF DESIGN



Primary digesters are usually the fixed roof type, and secondary digesters are usually the floating roof design.

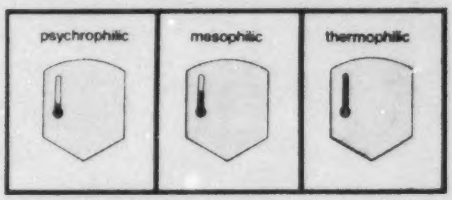
The floating roof allows for unsteady sludge draw off rates so that disposal may be periodic rather than constant. To prevent the roof from falling to the bottom of the digester, steel or concrete corbels project from the wall of the digester.

GAS HOLDING ROOF



Digesters that serve the third function - gas holding require a special roof design. The roof of this type of digester floats high above the sludge and is totally supported by the gas pressure in the digester. Since gas pressure holds up the roof, its position is controlled by rates of gas produced and gas or sludge draw off.

Classification by Temperature



Besides classifying digesters as to function and roof design, they may be classified by the operating temperature of the digesting sludge. There are three typical temperature ranges: psychrophilic, mesophilic, and thermophilic, the most common of which is the mesophilic.

The length of time required for digestion to come to completion is a function of the temperature range. Operating within the mesophilic range at 95-98°F will normally complete digestion in 20-30 days.

DIGESTION TIMES AND RANGES

	Digestion Times	Temperature Ranges
Psychrophilic	50-180 days	50°-68°
Mesophilic	5-50 days 20-30 days	68°-113° 95°-98°
Thermophilic	5-12 days	above 113°

Boilers and Heat Exchangers

This temperature should not vary more than 1°F per day. To maintain this temperature, a boiler and heat exchanger of some type are necessary.

The boiler is usually of the low pressure type (less than 300 psi) and fired by the methane in the digester gas. Using the digester gas to fire the boiler reduces overall energy requirements and makes the anaerobic digestion process an energy producer rather than a consumer.

Besides having the digester gas available, an alternative energy source such as natural gas is usually required for start up and as back up at times of digester upset. During these incidents, the quality of the gas will deteriorate to the point that proper temperature can no longer be maintained.

Along with the boiler, there must be a heat exchanger. There are three basic types: internal, direct gas and external.

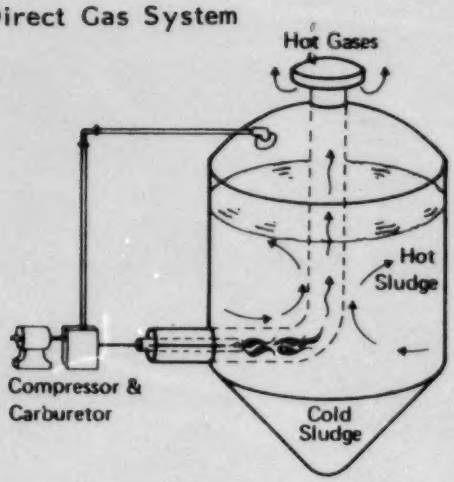
Internal heat exchangers are usually the hot water type and consist of a set of internal coils through which the hot water passes.

Internal heat exchangers are difficult to maintain and require efficient mixing to prevent stratification of the sludge.

Another type of internal heat exchanger is the steam injection type - with this style of heat exchange, live steam is bubbled through the digesting sludge both heating and mixing.

This type of heating adds extra water to the

Direct Gas System

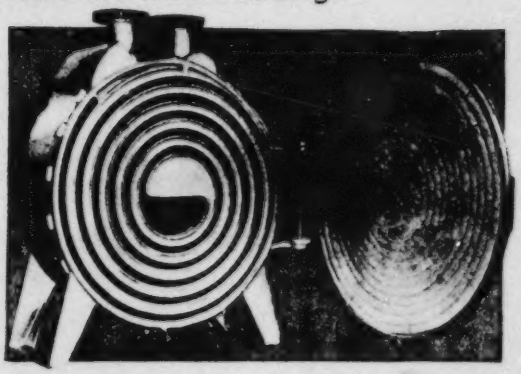


sludge. Further more it requires special chemical treatment of the boiler make up water and continous maintenance of check valves to prevent back flow of sludge into the boiler.

Direct gas systems consist of an open flame contained in a hollow tube below the sludge surface. This type of heat exchanger both heats and mixes.

This type of system offers an obvious safety problem; that is, if the methane within the digester is ignited by the open flame, a violent explosion will occur.

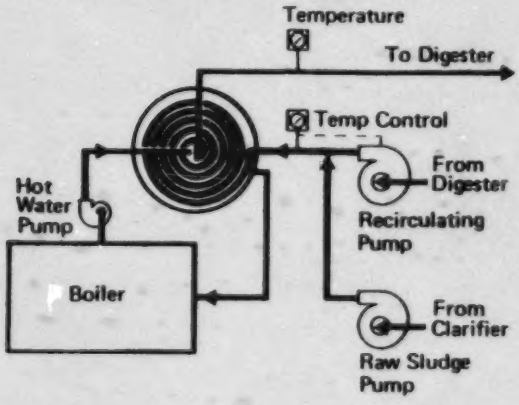
External Heat Exchanger



External heat exchangers are much easier to maintain than either internal or direct flame and are, therefore, more common. So, let's look at the process when one of the many external heat exchangers is used.

Hot water from the boiler is passed through a set of tubes within the heat exchanger. Partially digested sludge is mixed with raw sludge by the sludge recirculation pump and then circulated through the spaces between the hot water tubes and then to the digester.

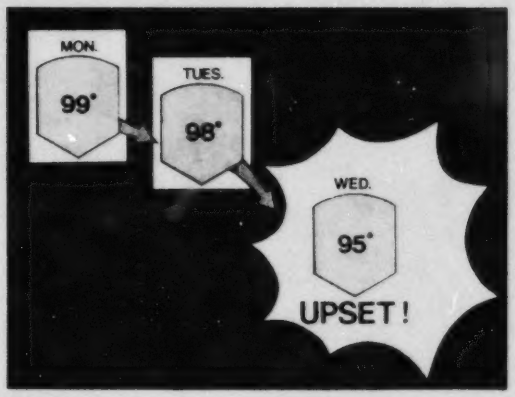
External Heat Exchanger System



The mixing of partially digested sludge with raw sludge improves heat transfer efficiency. The recirculation pump helps with mixing.

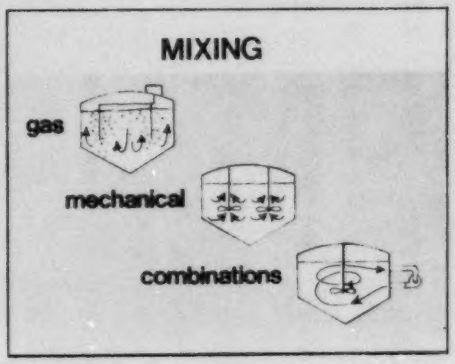
To maintain the heat exchanger efficiently the tubes must be cleaned on a regular schedule.

Controlling the temperature of the sludge and the overall energy efficiency of the system is dependent upon the B.T.U. value of the gas



and the efficiency of the boiler and heat exchanger. The efficiency is also affected by the temperature and feed rate of the re-circulating digested sludge.

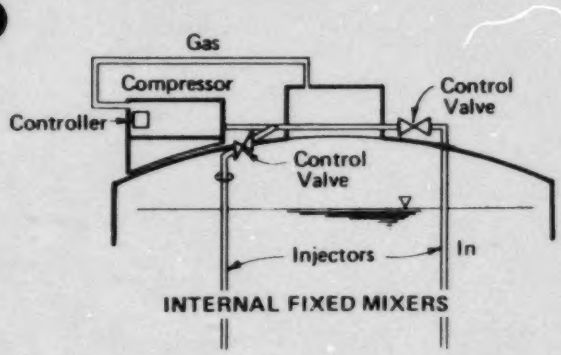
Remember, the temperature must not vary more than $1^{o}F$ per day. Fluctuations of greater than one degree/day, even though within acceptable temperature ranges, will cause digester upset.



Mixing Systems

As has been mentioned before, the digestion of raw sludge cannot take place unless the microorganisms within the digester can come in contact with the volatile solids within the sludge.

This contact is enhanced by continual mixing of the digesting sludge. Several methods of mix are used. They include:



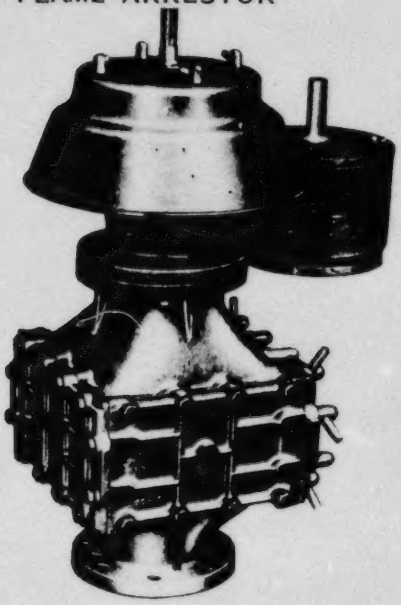
Compressing the gas that is produced and forcing it back through the digesting sludge, or one of several types of mechanical mixers, or a combination of mechanical mixers and pumps, such as the heat exchanger recirculation pumps.

Gas System

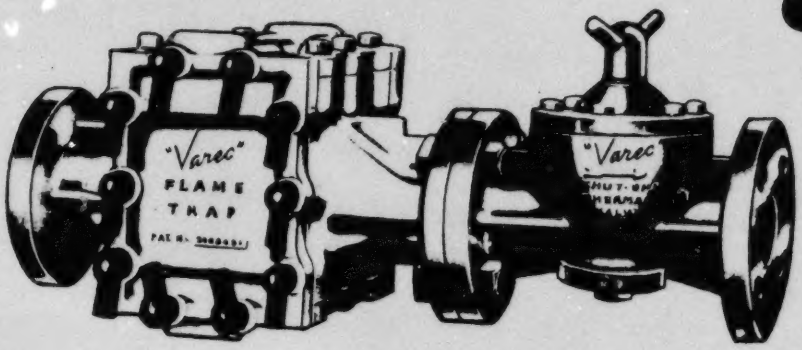
As has been mentioned previously, one of the major by-products of the anaerobic digestion process is the production of digester gas, mostly methane.

Because of the explosive nature of the gas, special equipment is required for safe handling. This is true regardless of the major use of the gas.

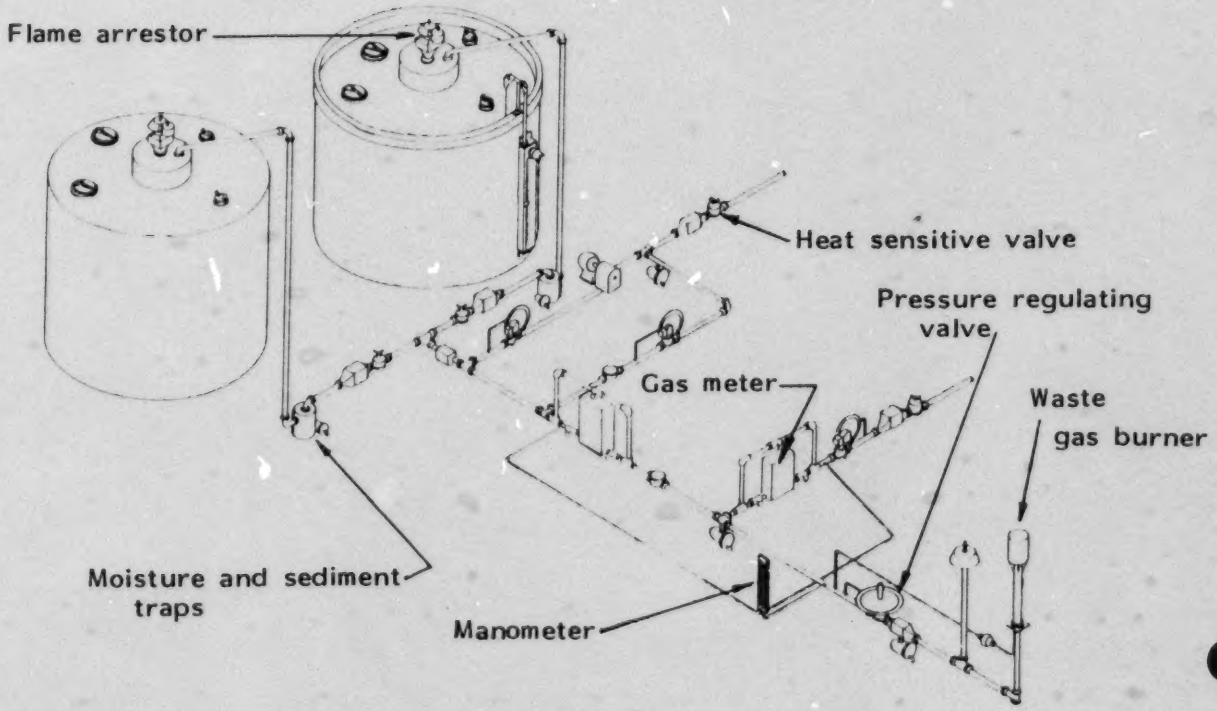
FLAME ARRESTOR



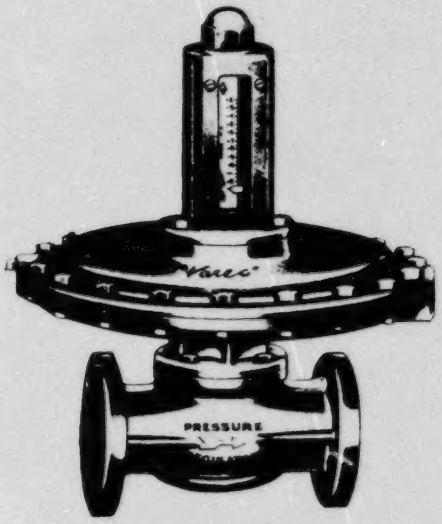
HEAT SENSITIVE VALVE



To prevent flash fires in the digester, flame arrestors are installed on the top of the digester as well as on all other gas line exit points. Heat sensitive valves are installed at various points in the gas system to help prevent explosion that could result from a fire within the gas system.



PRESSURE REGULATOR



Pressure within the gas system is maintained by a compressor and various pressure regulation valves.

The functional quality of the gas is improved by the reduction of moisture and sediment by moisture and sediment traps.

The rate of gas flow is measured by sharp edged orifices and indicated on manometers.

Gas consumption is measured by a typical gas meter.

When digester gas systems are properly designed they operate safely while controlling a steady pressure and removing sedimentation and moisture plus monitoring both gas flow and consumption.

Digester gas is not easily stored in a typical gas container due to its corrosive and explosive nature. Therefore, any excess that is produced is consumed via a waste gas burner.

OPERATIONAL CONTROL

*bacteria
*food
*loading
*mixing
*environmental conditions
*time

To obtain optimum digestion from the digester, six factors must be controlled.

They are bacteria, food, loading, mixing, environmental conditions and time.

The bacteria of major concern are the methane producers which are strict anaerobes. To protect their environment, all air must be prevented from entering the digester.

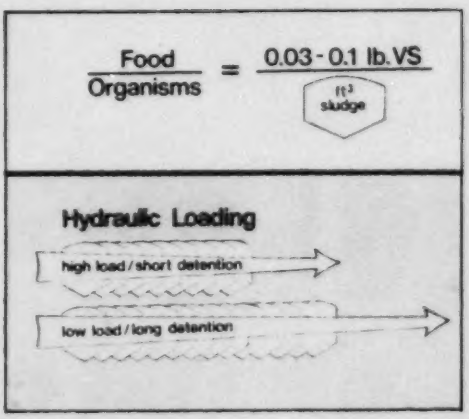
These organisms are rather slow in their digestion process; therefore, a ratio of 20 times more seed organisms than food is required. That is, each day, only one lb. of food should

be fed for each 20 lbs. of organisms in the digester. That is why it normally takes 20 days or more to complete digestion.

The food should be of high quality.

To be high quality, the raw sludge should contain a low volume of water. It should contain no toxic materials and have a stable pH. The rate and frequency of feed must be constant.

Loading refers to both the food to organisms ratio and the hydraulic loading.



The food to organisms ratio for conventional operations will range from 0.03 to 0.1 lbs. of volitile solids per cubic foot of digester sludge. Hydraulic loading affects detention time. The detention time must be long enough to allow for ccmplete digestion, which may be 20 days or more.

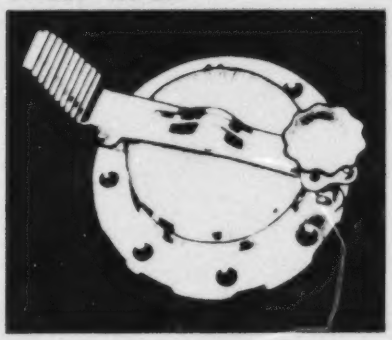
The food must mix with the organisms. Mixing may be natural or artifical. However, artifical mixing gives the best results and reduces dead spots.

As mentioned before, the environmental conditions must be strictly anaerobic and a VA to Alk ratio of 0.25 or below will maintain a steady pH.

The pH should be maintained between 6.8-7.2. The volatile acid should be in the 50-300 mg/l range and the alkalinity should be maintained in the 3000-6000 mg/l range. For best results, a VA to Alk ratio of 0.25 or below will maintain a steady pH.

EFFECT OF TEMPERATURE ON DIGESTION TIME	
Temperature (Deg. F.)	Digestion Time (Days)
59	67.8
68	46.6
77	37.5
86	33.3
95	23.7
104	22.7
113	14.4
122	8.9
140	12.6

THIEF HOLE



Digestion time is relative to temperature and controlled by loading - that is at 95-98°F a detention time of 20-30 days should be maintained.

Sampling and Testing

To control the digester, it is necessary to monitor regularly at various points. Samples should be collected from raw sludge, digester sludge, digested sludge, supernatant and gas. Digested sludge is usually collected through special sampling holes called thief holes.

Samples collected from these points should be evaluated by laboratory tests. Tests such as pH, % of moisture, temperature, alkalinity, and volatile acids are among the many required monitoring tests.

Raw sewage, digesting sludge, digested sludge and supernatant are all checked for pH and temperature. These tests should be run and compared at least daily.

Sludge and gas flow are measured at all entrance and exit points on the digester.

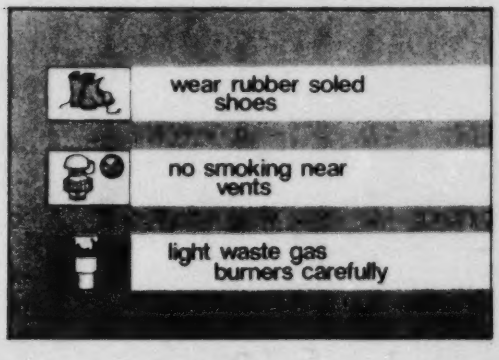
To determine the efficiency of the digester, total solids, % of moisture and volatile solids are run on the raw sludge and compared with digesting and digested sludge. These same tests are conducted on the supernatant to determine its quality and ultimate effect on the other treatment processes.

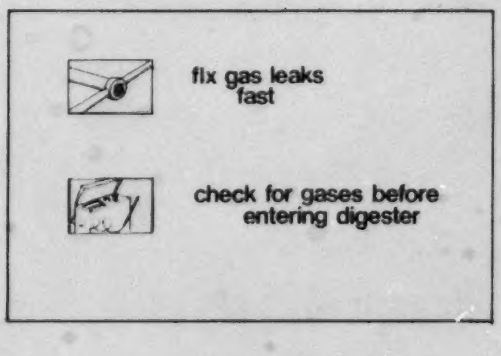
The percent of CO_2 in the digester gas as well as flame color indicate gas quality and digester performance. To determine the effect of supernatant on the other treatment processes, both BOD and S.S. are monitored.

The ultimate control test for digester operations are volatile acids and alkalinity. This ratio indicates impending changes in the pH of the digester and, thus, the health of the methane formers. A change in VA/Alk ratios will indicate possible digester problems long before a change in pH can be measured.

For best control trend charts of all parameters should be established with 30 day moving averages.

SAFETY PRECAUTIONS





Safety

To prevent accidents with digesters, the following precautions should be considered. Wear rubber soled shoes when walking on the roof, never smoke around the digester vents, relight the waste gas burner with caution.

Fix gas leaks ASAP. Never enter a partially full or empty digester without checking for oxygen depletion and explosive gases.

During this lesson, we have seen that digesters are classified three ways: by function, by roof design, and by operating temperature. The mesophilic temperature classification is the most common.

We learned that digester temperature is controlled by a heat exchanger and that the sludge temperature must be controlled within 1°F/day.

We looked at several types of mixers and learned that mixing improves digestion.

We previewed the basic components of the gas system and learned that the system is designed to control the pressure of the gas, remove sediment and moisture, measure flow and consumption and protect the digester from fire and explosion.

We saw that for proper operational control, the digester must be monitored and special control tests run on the collected samples.

And, finally, we discussed some general safety precautions that should be considered when working in and around digesters.

References

"Operations Manual; Anaerobic Sludge Digestion;" EPA, 430/9-76-001, Cinncinati, OH, 1976.

"Manual of Practice #11 Operation of Wastewater Treatment Plants," WPCF, Lancaster Press, Lancaster, PA, 1976.

"Operation of Wastewater Treatment Plants", Kenneth D. Kerri, Sacramento State College, Sacramento, CA, 1980.

ANAEROBIC DIGESTION II

WORKSHEET

1. Digestion may be classified by function. On the list below, place an "X" beside the three terms used to describe these three functions:

   _____ a. digestion
   _____ b. primary
   _____ c. solids reduction
   _____ d. conditioning
   _____ e. secondary
   _____ f. gas production
   _____ g. energy cost savings
   _____ h. gas producers
   _____ i. gas holding

2. Find the correct name for this digester in the above list and write the corresponding letter in the following blank:_____.

3. Select the proper name for the most common digester operating range.

   _____ a. mesophilic
   _____ b. psychrophilic
   _____ c. esophilic
   _____ d. thermophilic
   _____ e. none of the above

4. Select the temperature range for the most common digester operating range.

   _____ a. 65-78^{o} F
   _____ b. 79-95^{o} F
   _____ c. 95-98^{o} F
   _____ d. 98-108^{o} F
   _____ e. none of the above

5. For a normally operated anaerobic digester operating within the typical temperature range, complete sludge digestion should take place in:

   _____ a. 10-20 days
   _____ b. 20-30 days
   _____ c. 30-35 days
   _____ d. 40-50 days
   _____ e. none of the above

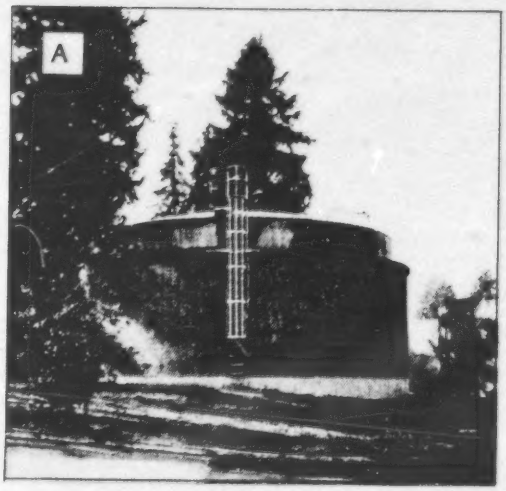
6. Using the pictures below, identify each of the digesters by roof design.

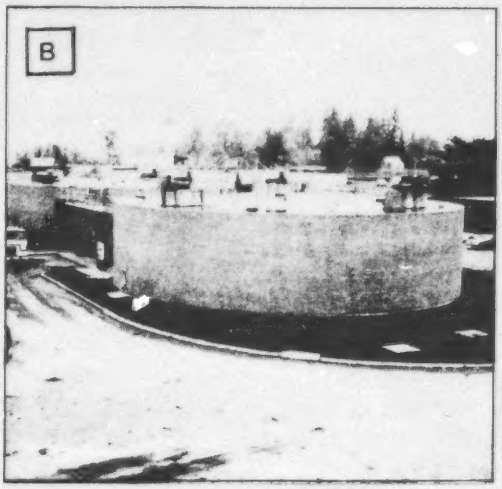
A. _____

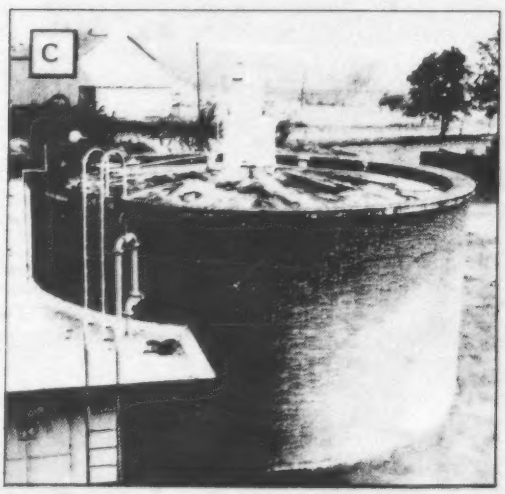
B. _____

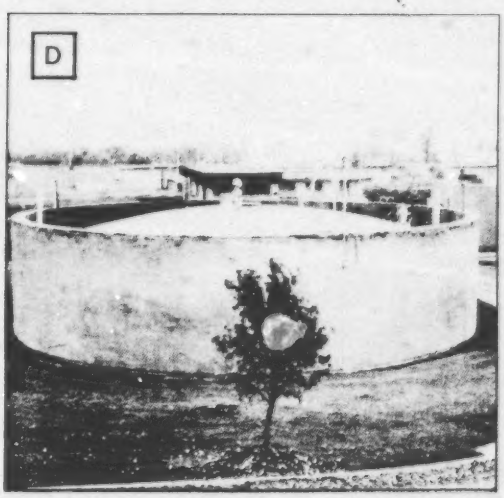
C. _____

D. _____









7. In order to maintain an anaerobic digester in optimum condition, the digester sludge temperature should not change more than _____ degrees per day.

_____ a. 4
_____ b. 3
_____ c. 2
_____ d. 1
_____ e. none of the above

8. From the list below, select the three most common types of heat exchangers.

_____ a. internal combustion engine
_____ b. direct gas flame
_____ c. low pressure
_____ d. coil type
_____ e. internal
_____ f. draft tube
_____ g. external
_____ h. boiler

9. From the previous list, indicate the type of heat exchanger that offers the easiest maintenance.

_____

10. The major purpose for mixing is to: (select one)

_____ a. bring food and microorganisms into contact.
_____ b. break up the scum blanket
_____ c. reduce energy requirements by circulating heated sludge.
_____ d. release gas from the sludge particles.

11. Match the list of gas handling equipment on the left with the list of functions on the right. (An answer may be used more than once.)

_____ flame arresters	
_____ waste gas burner	a. improve gas quality
_____ gas meter	b. measure gas consumption
_____ heat sensitive valve	c. measure gas flow
_____ sharp edged orifice	d. safety
_____ moisture traps	e. disposal of excess gas
_____ sediment traps	

12. Typical volatile solids/ft.^{3} loadings for an anaerobic digester might be:

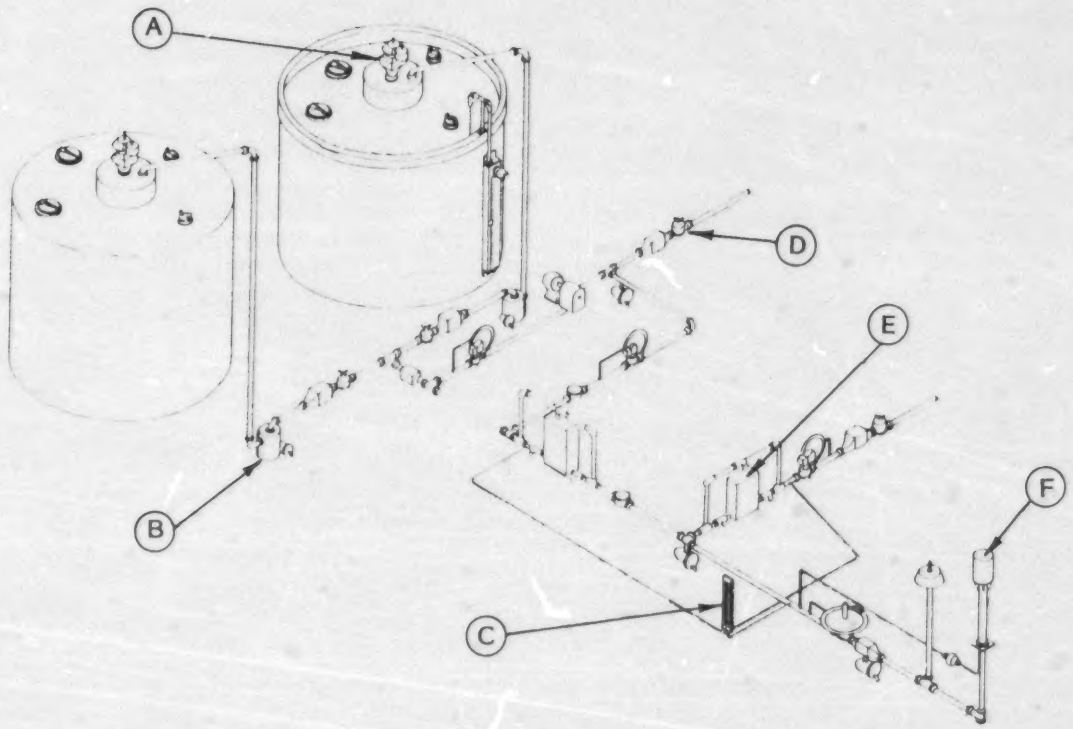
_____ a. 0.004 to 0.04 lbs./ft.^{3}

_____ b. 0.04 to 0.4 lbs./ft.^{3}

_____ c. 0.03 to 0.1 lbs./ft.^{3}

_____ d. 0.03 to 1.0 lbs./ft.^{3}

_____ e. all of the above



13. Using the drawing above, match the items indicated with the description.

_____ flame arrester

_____ waste gas burner

_____ gas meter

_____ heat sensitive valve

_____ moisture and sediment traps

_____ manometers

14. The most common volatile acids to alkalinity ratio for an anaerobic digester would be:

_____ a. > 0.25

_____ b. > 150

_____ c. 0.4

_____ d. < 0.25

_____ e. < 0.4

15. Using the diagram below, indicate what material is being sampled at each point.

_____ supernatant

_____ raw sludge

_____ digesting sludge

_____ gas

_____ digested sludge